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FEASIBILITY OF COMPUTER SIMULATION OF AN IMAGERY INTERPRETATION--ETC(U)
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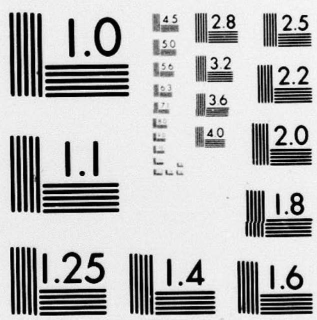
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(6) **FEASIBILITY OF COMPUTER SIMULATION OF AN IMAGERY INTERPRETATION SYSTEM**

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FOREWORD

Under the Surveillance Systems RDT&E Project, the COMPONENT INTEGRATION Task seeks to evaluate total system configurations of men, machines, and procedures, using an experimental computer-based interpretation facility.

The present feasibility study was conducted by Wayne H. Jones of the Advanced Systems Division, System Development Corporation, under contract to the Department of the Army. Research Memorandum 66-1 is based on a search of the literature for reports of similar simulations and for characteristics of systems which have been--or could be--amenable to simulation. Concurrently, system analyses of image interpretation systems were conducted for the purpose of formulating a suitable framework for simulation. In particular, models were sought which contained man-machine interactions as parameters.

FEASIBILITY OF COMPUTER SIMULATION OF AN IMAGERY INTERPRETATION SYSTEM

A means of quickly and reliably evaluating alternative tactical image interpretation facilities is needed. The objective of the present study was to examine the feasibility of simulating image interpretation systems on a computer in order to aid in the selection of promising man-machine configurations for further laboratory and field evaluation.

Research in image systems is complicated by the many factors that can influence system performance. Input load, system personnel, operations, equipment, environment, and required system outputs can critically affect system performance. Each of these factors can, in turn, be divided into many component factors or variables which separately or in combination affect performance. Input load, for example, can be expressed in terms of batches of imagery varying in type, length, number of frames, scale, quality, target density and distribution, terrain type, etc. Even more factors or variables must be considered in analyzing system operations, equipment, and environment. The difficulty of controlling or systematically varying any large number of these variables even within a well-designed experimental facility has acted as an inhibitory influence on the scope and direction of experimental research conducted in image systems.

The aim of the present study was to investigate the feasibility of using a computer to simulate the factors influencing system performance. The goal of such simulation is to develop tentative configurations for the effective use of personnel and equipment within image systems, configurations which can later be tested experimentally. If appropriate representation of system imagery inputs, reporting requirements, interpreters, equipment, processing procedures, and intelligence products can be achieved in a model, then the manipulation of the many parameters involved could probably be achieved more easily using a computer than in the laboratory. Only those equipment-personnel configurations and processing which showed the most promise of meeting the system's input load and output objectives would then be tried out in the Surveillance Research Laboratory of the U. S. Army Personnel Research Office (U. S. APRO) or in field system tests and operations.

For the simulation to be effective, it is necessary to construct a valid representation of the probability of target detection and identification in terms of characteristics of imagery, interpreters, equipment, and procedures. Deterministic and stochastic models and the simulation of system performance using either analytical or Monte Carlo methods were considered in this feasibility study.

GENERAL MODEL FOR SYSTEMS ANALYSIS

The effectiveness of a system can be represented by the equation

$$E = f(x_i, y_j)$$

where E is the effectiveness, x_i the variables subject to control, and y_j the variables not subject to control (1). Restrictions on the variables may be expressed in supplementary equations and /or inequalities. In these terms, a problem of interest is to determine the values x_i which maximize E for various given sets of values of y_j. If the function f can be expressed mathematically, the maximum value of E can sometimes be found by mathematical analysis. If direct analysis fails, there are many schemes which, through an iterative process, yield an approximation to the maximum. Systems solvable by these means include those in which inventory, allocation, waiting time, replacement, and competitive processes are involved. Of these, competitive models are perhaps the most difficult because the solution depends on assumptions about the behavior of opposing elements. Quite often some of the variables are random, in which case the objective is usually the maximization of the expected value of E. For many large systems, however, no tractable mathematical model is available. For some of these systems, models of system components are known, but the total systems are too complex for mathematical analysis. Computer simulation is often valuable in these cases. If, as is likely, random variables are present, then estimates of means and variances of system effectiveness may be obtained for various values of the control variables x_i. These may be used as a basis for selection of a small set of promising system configurations for futher investigation. If the computer model is a sufficiently precise representation of the real system, the last step is unnecessary; unfortunately, the precision of the model is seldom known.

Most large systems are further complicated by multiple criteria, or objectives. Usually, one criterion is maximized at the expense of the others, and the best choice from several configurations cannot be determined without recourse to judgment factors external to the model.

IMAGE SYSTEM APPLICATION

For imagery interpretation, system effectiveness measures are usually taken to be accuracy, completeness, and timeliness. Control variables x_i are represented by sensors, platforms, quality and quantity of imagery, interpreter aptitude and state of training, and procedures. Variables y_j not subject to control are represented by target distribution, weather, terrain, and mission.

The feasibility of computer simulation of a system depends heavily on the goals. To the extent that these goals include determination of the effect on system performance of changing certain variables, the system model must provide for these variables, directly or indirectly. For example, a particular sensor need not be represented explicitly by a single control variable. The representation might be a point in the parameter space of image quality. In such a model, nonexistent sensors could be tested, provided, of course, that the validity of the model extends to the appropriate region of the parameter space.

The spectrum of control variables of interest in image systems is illustrated in Table 1. Note that most of the variables are discrete (usually two categories) rather than continuous. Categorical variables are inherently more difficult to model. In the first place, separate prediction equations are required for each combination of categories--unless the interactions are negligible. The usual analysis of variance model for 20 dichotomous variables involves 211 parameters, if only the main effects and two-factor interactions are included. In the absence of knowledge of the structure of these variables, the parameters must be estimated from a very large and complex experiment. But the data resulting from this experiment would already contain the answers to the questions which would be asked of a computer simulation, namely, which combination of variables produces the best system performance, and how does one configuration compare with another? Therefore, computer simulation of this kind of model will not provide any new information.

Other investigators have reached similar conclusions concerning the feasibility of this type of computer simulation. In an unpublished Project Michigan report (3), DeVoe and Hoagbin state:

> "A complex man-machine system, such as a Tactical Image Interpretation Facility, does not lend itself to ordinary engineering analysis. It is not possible to write functions relating performance to design variables that lend themselves to mathematical operations. Many parameters, for example, image quality, cannot be quantified satisfactorily."

In a more general context, the following paragraph is found in Muckler and Obermayer (4):

> "A number of mathematical models can be fitted to human operator data, but only a quasi-linear model has been extensively tested. Simulations are becoming increasingly sophisticated, but field tests and empirical methods are used because human performance is unpredictable. Despite the large amount of data gathered, little understanding of it has emerged. Concepts and theory remain in a state of flux."

Ornstein and others (5, 6) of North American Aviation have developed an elaborate computer model of search system performance which deserves mention. In this model, there is one vehicle or platform which carries one or more observer-display combinations. Only one target is assumed,

Table 1

IMAGE SYSTEMS CONTROL VARIABLES[a]

1.	Imagery Screening and Hot Reporting (screening techniques, multiple displays and display times)
2.	Report Composing (oral, typewriter, or special keyboard?)
3.	CRT vs. Projection Viewing (photo, IR, SLAR)
4.	Direct Viewing vs. Projection Viewing for Screening
5.	Comparative Viewing (methods of presentation of imagery)
6.	Team Interpretation Techniques
7.	Optimal Viewing Angles
8.	Direct vs. Projected Magnification of Imagery
9.	Resolution Loss in Projection
10.	Manual vs. Automated Reference Retrieval
11.	Contribution of Keys and Other Reference Material
12.	Multisensor Imagery - Comparative Cover (value of partial or complete IR, SLAR records in photo interpretation)
13.	Immediate and Detailed Interpretation-Parametric Data on Methods of Search (instructions to II varied)
14.	Role of Officer-in-Charge in Assignments and in Resolving Interpreter Disagreements
15.	Performance of IIs on Specialized Interpretation Tasks (interchangeability of IIs)
16.	Work-Rest Cycles
17.	Positive vs. Negative Transparencies
18.	Effect of Background Noise
19.	Forced vs. Self-Pacing and Viewing
20.	Discrete vs. Continuous Movement of Imagery
21.	Manual vs. Automatic Plotting
22.	Effect on Target Location of Inaccuracy of Platform Location
23.	Vertical, Oblique, Panoramic Imagery
24.	Manual vs. Computer Mensuration
25.	Manual Methods of Measuring Height
26.	Cursor Positioning Accuracy

[a]Abstracted from Applied Psychology Corporation Interim Report (2).

and the mission ends when the target has been identified (correctly or not) or when the target area has been completely searched without a positive identification. The search is performed in real time from dynamic displays, and the search path may be modified to re-examine a ground patch if any observer reports detection but not positive identification. The model is essentially a *Markov chain over discrete time intervals* and the target area segments, with 13 states defined by various response conditions. The necessary transition probabilities are determined empirically.

There are obvious differences between this type of search and tactical imagery interpretation within an interpretation facility. In particular, the assumption of a single target in a mission makes this process quite different from the one usually studied experimentally within the Surveillance Research Laboratory. Of greater significance, however, is the dependence of system performance on the transition probabilities. These probabilities are clearly functions of observers, sensors, platforms, terrain, weather, and many other factors. In order to determine the effect on system performance of varying any of these factors, it is necessary to provide the model with probability parameters appropriate to each system configuration to be studied. Within the present state of knowledge, it does not appear that these detailed aspects of the search process are any better known than total system performance.

Another type of simulation which should be mentioned calls for human beings to play an active part in the simulation. Such simulations have been conducted in the Logistics Systems Laboratory of the Rand Corporation in order to assist the Air Force in the evaluation of logistics policies. Simulations were conducted using experienced logistics officers, with parts replacement needs computed from failure rate distributions. Murray Geisler (7) reports that each of three simulation experiments cost more than $1,000,000, lasted about two years, and involved more than 100 people. Further details on the programming task are available in Little and Shelton (8). These experiments are illustrative of the considerable effort required to simulate a complex system, even when man, the most complex system component, is not simulated.

DISCUSSION AND CONCLUSIONS

Faced with the problem of system design, which includes choices of hardware (including some not yet developed), allocation of functions among men and machines, and specification of procedures, designers may find that it is too expensive in both time and money to build even prototypes of versions to be considered. On the other hand, the large number of interactions present in large scale systems means that even the most carefully designed set of flow charts and specifications may not result in an operating system which satisfies the requirements. An alternative course of action is to construct a simulation model which can be programmed and run on a computer. The model may be partially validated on the current operational system, but the ultimate value of the simulation lies in its

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use in an untested region of the parameter space, namely, that which contains the possible systems to be considered but not yet built.

It seems apparent that only system configurations whose characteristics are representable within the model parameter space can be evaluated by using the model. Put another way, the effect of a particular variable on system performance cannot be determined unless that variable is present in the model, explicitly or implicitly.

As of now, the surveillance system performance measures of accuracy and completeness cannot be expressed as functions of the kinds of variables appearing in Table 1, which are typical of problems being studied in U. S. APRO. The reason seems to be that the human function of image interpretation is complex and little understood, and cannot be broken down into components whose operation is well understood. This state of affairs is in sharp contrast to subsystems consisting of hardware only, where total performance can be predicted because of detailed knowledge of component operation. It is therefore the conclusion of this study that computer simulation of an image interpretation system is not currently feasible.

The feasibility of simulation should be explored again in the future when the data necessary for the successful conduct of a computer simulation have been collected.

The conclusion applies only to accuracy and completeness; recent work by U. S. APRO and Nortronics suggests the usefulness of a computer model of the system as a network of queues of subtasks, where estimates of subtask performance times are provided initially by expert judgment and refined later through observation in the laboratory. It will be assumed in this model that the times are for an average level of performance. This assumption is troublesome, but it may be removed eventually or alleviated by gradually incorporating accuracy and completeness criteria as knowledge of these variables increases with laboratory experimentation. At any rate, there is a large body of experience to support the use of exponential distributions of service time to describe times of execution of all sorts of tasks. A characteristic property of this family of distributions is that the number of tasks completed in a fixed time interval has the Poisson distribution. The usefulness of such a model does not depend on this or any other specific distribution, however. At the very least, it would perform time line analyses on the computer which are laborious and time consuming when done by hand.

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